

Unlimited Release  
SAND85-2597  
December, 1985

TEST OF DEPARTMENT OF ENERGY STRATEGIC PETROLEUM RESERVE  
CAVERN 102 AT BAYOU CHOCTAW

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Abstract

Two brine pressure tests were conducted on the Department of Energy Strategic Petroleum Reserve, Cavern 102, at Bayou Choctaw from November 28, 1984, to December 18, 1984. A nitrogen leak test was then conducted from December 18, 1984, to January 9, 1985, on the Cavern 102 entry well. These tests were conducted to provide data for the State of Louisiana Cavern Certification Program. This program is covered by Statewide Order No. 29-M which provides rules and regulations pertaining to the use of salt dome cavities for storage of liquid and/or gaseous hydrocarbons. The test results indicate that the oil leak rate from Cavern 102 is approximately zero bbl/yr. Cavern 102 will be traded to Allied Chemicals' Union Texas Petroleum Division for their Cavern 17 at Bayou Choctaw per Exchange Agreement dated March 1982.

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## Introduction

Louisiana Statewide Order No. **29-M** sets forth rules and **regulations** pertaining to the use of salt dome cavities for storage of liquid and/or gaseous hydrocarbons. These rules and regulations, which are promulgated by the Commissioner of Conservation, require a capacity determination of the storage chamber and a complete inspection of the Christmas tree and casing. They further require repeat checking at five-year intervals.

A plan, Reference 1, was developed to meet these rules and regulations and to provide guidelines for Strategic Petroleum Reserve (SPR) storage cavern testing. This plan includes two brine pressure tests of the cavern and a nitrogen leak test of each entry well. The first brine test requires pressurizing the cavern to maximum test pressure and then shutting it in for at least one day to observe **wellhead** pressures. For the second brine test, the cavern is depressurized from maximum test pressure to maximum operating pressure and shut-in for at least two days to observe the **wellhead** pressures. These two brine pressure tests provide an indication of mechanical integrity of the cavern as they provide for a comparison of one cavern to all others at the site and they provide for a comparison of the cavern response at five-year intervals. Although these two brine tests are not required in the above **29-M** order, they do provide data that would help define a potential problem, and it has been agreed with the Department of Energy (DOE) and the operations contractor that they be retained as a necessary part of the testing program.

The nitrogen leak test of the entry well does provide an indication of fluid loss from the cavern and does provide data for evaluating the Christmas tree. The SPR oil loss rate goal has been defined as no more than 100 **bbls/yr** per cavern.

Cavern 102 at Bayou Choctaw was tested jointly by POSSI and Sandia Labs during the interval between November 28, 1984, and January 9, 1985. Testing was conducted in accordance with Reference 1.

**Cavern 102** was solution mined by DOE to be traded to Allied Chemicals' **Union** Texas Petroleum Division for their **Cavern 17** at Bayou Choctaw. **Cavern 102** will be used for ethane storage and **Cavern 17** will be used by DOE for crude oil storage.

### Well/Cavern Description

A complete description of the well is given in the "**Well History**" which is Reference 2. This defines the well as it was constructed prior to development. Reference 2, in conjunction with Reference 3, defines the configuration of the hanging strings at the time of the second nitrogen leak test conducted between May 25 and June 7, 1982.

Figure 1 defines the well and the configuration of the hanging strings as they existed during this test.

Figure 2 is a schematic of the sealing arrangement for the **14-inch** casing. The sealing arrangement used during the well testing that was conducted in May and June of 1982 leaked. The arrangement shown in Figure 2 proved to be successful for this test.

Reference 4 illustrates the size and shape of the cavern as tested.

The Sonar Caliper Report of Reference 4 describes the cavern as having its roof at 2640 ft and a narrow chimney that tapers outward to a 27 ft diameter at 2652 ft. The cavern then opens to an average diameter of 178 ft at 2655 ft and reaches the maximum average diameter of 226 ft at 2780 ft. From 2780 ft to 2960 ft. the cavern is essentially cylindrical and it begins to slowly taper inward below 2960 ft. At 3280 ft, the average diameter is 180 ft. The cavern then tapers inward rapidly to a diameter of 57 ft at 3460 ft. The volume of the cavern, as determined from recent sonar data, was **5,462,065** barrels.

### Background

Reference 5 discusses previous testing procedures of the well prior to cavern development and their results. A summary of previous testing includes the following:

1. A 45-hour brine test June 22-25, 1981, indicated a brine leak rate of 19.3 bbls/yr.
2. A nitrogen test July 6-11, 1981, was conducted with nitrogen in the 14 x 10-3/4-inch annulus and inside the 10-3/4-inch hanging string because of leaks at the joints of the 10-3/4-inch hanging string. The pressure decayed at a rate of 0.51 psi/hr over a 72-hour test period. During this period a significant nitrogen leak was noted through a crack in the 20-inch casing about 5 ft below the Braden-head flange.
3. After repairing the crack in the 20-inch casing, 10-3/4-inch and 7-inch hanging strings were run in August of 1981 to achieve the configuration tested. No attempt was made to repair a leak at the 14-inch casing hanger.
4. On May 4, 1982, a leak test of the 14-inch casing hanger seals was conducted. Nitrogen leaked past the upper O-ring into the well. At 700 psi, and after several hours, the pressure in the 20 x 14-inch annulus started rising. The nitrogen well leak test was conducted while keeping oil in the cavity between the hanger and the upper O-ring seals. This testing was conducted in May and June of 1982 and resulted in a calculated nitrogen leak rate of 32.1 bbls/yr.
5. The cavern was leached until October 1984, until its volume was 5,462,065 barrels. The cavern shape is illustrated by the Sonar Caliper Report of November 19, 1984. See Reference 4.
6. In November of 1984, a workover was performed and the resulting piping configuration is illustrated in Figures 1 and 2. By installing the 10-3/4-inch hanging string to 4913 feet and the 7-inch hanging string to 5104 feet, the cavern may be used in the future to produce saturated brine without impacting web thicknesses to adjacent caverns.

### Instrumentation

Wellhead pressures in the 10-3/4 x 7-inch annulus and in the 14 x 10-3/4-inch annulus were measured by use of a Sperry Sun "Mr. Six" pressure recording system. The 7-inch diameter suspended string was not monitored since it was used for brine flow and since it would have indicated the same pressure as the 10-3/4 x 7-inch annulus if the same density brine were present in both volumes. A separate strain gauge pressure probe at each pressure measuring point was connected to the "Mr. Six" unit. The "Mr. Six" unit sequentially digitized and then recorded on paper tape the wellhead pressure and probe temperature for each individual probe at preselected time intervals. The "Mr. Six" unit also provided a digital input to a data recording system provided by Sandia Laboratories (Sandia). Sandia's system consisted of two Hewlett Packard computers: an 85 and a 9915. The 9915 computer sorted the data provided to it by "Mr. Six" and then stored it in a magnetic tape cassette. The pressure data stored on the tape cassette were processed with the 85 computer.

In addition to the above-described pressure recording system, commercial dial-type pressure gauges were installed on each annulus. These gauges were read and recorded by the site operations personnel; the data from them are not a part of this report.

### Flow

Brine flow into Cavern 102 was measured by a Barton Model 200 orifice meter. The meter was located in the raw water supply line where it crossed the canal on its approach to Cavern 102. The brine for this phase of the test was pumped through the raw water pipeline from Cavern 19 by means of the diesel pumps located northeast of Cavern 102.

### Nitrogen Weight

Liquid nitrogen was supplied by NOWSCO. The weight of nitrogen injected into the entry well was measured by a mass-flow meter that was calibrated and set to read out in units of standard cubic feet.

The standard used is the volume of one cubic foot of nitrogen at 14.7 psia and 72°F. The weight of nitrogen injected into the cavern may be calculated from the volume data by using .0724 lb. of nitrogen per standard cubic foot. The nitrogen injected into the well flows from the liquid storage tank, through a vaporizer, a heater and the mass-flow meter before it enters the well.

During nitrogen injection into the lower cased part of the well and the open hole below the casing seat, the weight of nitrogen injected may be recorded simultaneously with pressure and nitrogen/brine interface depth. Data may be recorded at depth intervals as small as 10 ft in the cased part of the well and at depth intervals of about 5 ft in the open hole.

The purpose of the nitrogen weight measurements is to indicate **annulus** volume below the casing seat so that measured interface movements during the test can be related to changes of nitrogen volume. Weight measurements in the cased parts of the well, where volumes are known, may be used to establish a calibration factor for the weighing system. It has been determined previously that volumes calculated for the cased portion of wells from nitrogen weight measurements deviate significantly from known volumes.

### Interface Depth

Nitrogen-brine interface depths in the 14 x 10-3/4-inch **annulus** were measured by Perf-O-Log and by Micro Gage, Inc., using their standard **wireline** equipment including a standard density logging tool with a double-strength neutron source.

### Calibration

Dead-weight testing of the pressure transducer before and after testing showed them to be within 1/4th of 1% of the reading.

### Test Procedures and Results

The preliminary procedures for the test are outlined in Reference 6. The surface piping was prepared per Reference 6 and a sequence of testing events is listed in Table I. Reference 1 was also used as a procedural guide for testing.

#### Cavern Pressure Testina with Brine

Preparations for testing were completed on November 27, 1984, and 00:00 hours November 28, 1984, was defined as start time for the first phase of the test which was brine pressurization. Starting at 12:25 hours (12:25, 11/28/84) and at 0 psig brine **wellhead** pressure, the cavern was pressurized with brine from Cavern 19. The flow was measured by the orifice meter and its totalizer was read in ten-minute increments from the initial reading at 13:00 hours until the reading at 16:30 hours, at which time a leak occurred in the surface piping halfway between the **orif** ice meter and the wellhead. As a result of this interruption, the cavern was pressurized in two steps. The Pressure vs. Time Plot and the Pressure vs. Volume Plot for step 1 are illustrated in Figure 3. The pressurization rate for the cavern during step 1 was 149.8 **psi/hr** and the cavern strain rate was 13.785 **bbls/psi**. A total of 8280 bbls of brine was added before the cavern was shut-in at 16:30 hours at a **wellhead** pressure of 618.4 psig in the 14 x 10-3/4-inch annulus.

The leak in the surface pipe was not repaired because that particular line was designed to be used as a relatively low pressure brineline. The flow to the cavern was rerouted to bypass the leaking line and pressurization of the cavern resumed at 56:45 hours (08:45 11/30/84). An additional 1388 bbls of brine were added to the cavern during step 2 to increase the **wellhead** pressure in the 14 x 10-3/4-inch annulus to 705.9 psig. The Pressure vs. Time Plot and the Pressure vs. Volume Plot for step 2 are shown in Figure 4. The pressurization rate for this interval was 115.37 **psi/hr** and the cavern strain rate was 14.05 **bbls/psi**.

### Seven-Day Test at Maximum Test Pressure

At 57:37 hours (09:37, 11/30/84) the cavern was shut-in for a seven-day interval at maximum test pressure. During the shut-in interval the **wellhead** pressures for the 14 x 10-3/4-inch and the 10-3/4 x 7-inch **annuli** were recorded every sixty minutes throughout the seven-day interval. Plots of the data are shown in Figure 5. The pressure decreased in the 10-3/4 x 7-inch **annulus** at a rate of 0.44 psi/day over the seven-day interval and 0.727 psi/day in the 14 x 10-3/4-inch **annulus**. At 225:37 hours (09:37, 12/07/84) the first phase of the brine pressurization test (at maximum test pressure) was complete. The corresponding **wellhead** pressures on the 10-3/4 x 7-inch **annulus** and the 14 x 10-3/4-inch **annulus** were 692.2 psig and 697.3 psig, respectively.

### Eleven-Day Test at Maximum Operating Pressure

In preparation for the test at maximum operating pressure, 1204 bbls of brine were ejected from the cavern through the 7-inch hanging string. The resulting **wellhead** pressures at the 10-3/4 x 7-inch **annulus** and the 14 x 10-3/4-inch **annulus** were 599.5 psig and 576.5 psig, respectively. This occurred at 232:30 hours (16:30, 12/07/84). The cavern was then shut-in and monitored at 60-minute intervals for the seven-day duration of the maximum operating pressure test. The seven-day duration of the maximum operating pressure test was extended to eleven days due to the logistics of nitrogen availability for the next testing phase. The maximum operating pressure test portion was therefore extended but plotted data are presented in Figure 6 for just seven days. Figure 6 shows the **Wellhead Pressure vs. Time** Plots for both the 10-3/4 x 7-inch **annulus** and for the 14 x 10-3/4-inch **annulus**. At 489:00 hours (09:00, 12/18/84) the **wellhead** pressures were 616.8 psig and 592.1 psig, respectively, on the 10-3/4 x 7-inch **annulus** and the 14 x 10-3/4-inch **annulus**. This concluded the brine pressurization portion of the test.

## Well Pressure Test with Nitrogen

The nitrogen well test portion of the test was started on December 18, 1984. Start time was 00:00 hours, December 18, 1984. A reference density log was run by Perf-O-Log to establish the casing seat at 2499 ft. NOWSCO injected 32,833-ft<sup>3</sup> Standard Temperature and Pressure (STP) of nitrogen (2377.11 lbs.) into the well, which in turn increased the wellhead pressure on the 14 x 10-3/4-inch annulus to 1325.6 psig and to 621.2 psig on the 10-3/4 x 7-inch annulus. This moved the brine/nitrogen interface (I/F) to 1460 ft. The nitrogen was heated to 85°F prior to being injected into the well. Nitrogen injection was terminated at 17:15 hours on December 18, 1984, prior to locating the I/F at 1,460 ft. On December 19, 1984, nitrogen injection resumed and an additional 30,777-ft<sup>3</sup> (STP) or 2228.25 pounds were injected again at 85°F. At 34:09 hours (10:09, 12/19/84) the nitrogen injection was halted until the I/F could be verified at 2499 ft. The wellhead pressures on the 10-3/4 x 7-inch annulus and the 14 x 10-3/4-inch annulus were 623.3 psig and 1736.0 psig, respectively.

Volume changes in the borehole during the test intervals were calculated using the X-Y Caliper log data in Reference 7. Nitrogen injection resumed again and at 35:05 hours (11:05, 12/19/84) it was completed and the I/F was located at 2532 ft by means of the density log of Reference 8. An additional 11,362 ft<sup>3</sup> (STP) or 822.6 pounds of nitrogen had been added and the wellhead pressures were 627.2 psig and 1751.0 psig at the small and large annuli, respectively. This concluded the nitrogen injection. The total amount injected was 74,972-ft<sup>3</sup> (STP) or 5427 pounds. The pressure on the casing seat at this point was not the required 2000 psig so it was necessary to add 1186 bbl of brine to the cavern. This addition was completed at 88:20 hours (16:20, 12/21/84). The corresponding wellhead pressures on the small and large annuli were 713.1 psig and 1825.6 psig, respectively. At this point the cavern was shut-in and wellhead pressures were recorded hourly. The interface level was not

relocated after the addition of the 1186 bbls of brine.

Six days after the cavern was shut-in the nitrogen/brine I/F was located by density log at 2520 ft. This is shown in Reference 9. The log was taken at 227 hours (11:00, 12/27/84) and the **wellhead** pressures on the small and large **annuli** were 722.6 psig and 1834.3 psig, respectively. This point is defined as the end of the temperature stabilization period and as the start of the well nitrogen leak test. Plots of Pressure vs. Time for the temperature stabilization period are illustrated in the bottom graphs of Figures 7 and 8. These graphs are for the small and large **annuli**, respectively. The corresponding **wellhead** pressure increase rates were 1.67 and 1.448 psi/day.

The first nitrogen well test interval began at 227:00 hours (11:00, 12/27/84) and continued through 396:00 hours (12:00, 01/03/85). The Pressure vs. Time data for this time interval are illustrated in the middle graphs of Figures 7 and 8. These graphs indicate that the corresponding pressure increase rates were 2.156 and 1.84 psi/day. The interface was again located by density log, Reference 10, and found to be at 2519 ft. The interface had risen one foot to 2519 ft and the pressures on the small and large **annuli** were 737.5 psig and 1847.4 psig, respectively.

The second nitrogen well test interval began at 396.00 hours (12:00, 01/03/85) and continued through 539 .00 hours (11:00, 01/09/85). The Pressure vs. Time data for this time interval are illustrated in the top graphs of Figures 7 and 8. These graphs indicate that the corresponding pressure increase rates were 2.0 and 1.79 psi/day. The final density log, Reference 11, located the interface at 2518.5 ft and the pressures on the small and large **annuli** were 748.9 psig and 1858.3 psig, respectively. The interface had risen a half foot during this second week of testing. After the interface was located and the final pressure readings were taken, the test was complete and the nitrogen was released from the cavern.

## Calculations

### Cavern Elasticity

The total cavern elasticity calculated from the total brine fill of 9,668 bbls is 13.82 bbls/psi. For 5,462,065 bbls of brine with a brine elasticity of  $2.25 \times 10^{-6}$  bbl/bbl psi, the elasticity of the cavern fluid is 12.29 bbls/psi. Thus, the salt elasticity is  $13.82 - 12.29 = 1.53$  bbls/psi.

### Cavern Shut-In at Maximum Test Pressure

Cavern pressures during shut-in at maximum test pressure are shown on the expanded scale plots of Figure 5. Linear regressions of these data indicate pressure decay rates of 0.44 psi/day and 0.727 psi/day. Deviations of the data from linear variations with time generally indicate the decay rates are decreasing slightly with time, a trend generally expected following cavern pressurization and observed here.

### Cavern Shut-In at Maximum Operating Pressure

Cavern pressures during shut-in at maximum operating pressure following depressurization from maximum test pressure are shown on the expanded scale plots of Figure 6. Linear regressions of these data indicate pressure increase rates of 1.37 and 1.34 psi/day, respectively for the 10 3/4 x 7 and 14 x 10 3/4-inch annuli. Deviations of the data from linear variations with time generally indicate the pressure increase rates are decreasing slightly with time, a trend generally expected following cavern depressurization and shut-in but not observed here due to plot scales.

### Borehole Measurements

Based upon the data in Reference 7, the average cross-sectional area of the annulus in the open borehole between 2515 ft and 2520 ft was  $2.54 \text{ ft}^2$  (0.452 bbls/ft). This figure for cross-sectional area of the nitrogen-filled annulus volume will be used for leak rate calculations.

### Nitrogen Leak Tests

The linear regressions of the pressure results over the test periods are indicated in the previous section and in Figures 7 and 8. Calculations of leak rate corresponding to pressure decay rates are based upon the equation of state:

$$W = \frac{144 PV}{RT}$$

where W weight, lbs.  
P pressure, psia  
V volume, ft<sup>3</sup>  
R gas constant, 55.159 ft/°R for nitrogen  
T temperature, °R, degree Rankine

Since the average temperature in the well and the ratio of average pressure to measured **wellhead** pressure can be assumed constant in the absence of gross interface movements or gross **wellhead** pressure changes, the volume loss at initial density for each test interval may be approximated by:

$$\Delta V_{id} \approx V_0 \left( - \frac{\Delta P}{P_0} - \frac{\Delta V}{V_0} \right) \quad (P. 23 \text{ Ref. 1})$$

The results are given in Table II. For the first test interval the calculated leak rate was -17.34 **bbls/yr** of nitrogen at 1849 psia. For the second test interval the calculated leak rate was -23.63 **bbls/yr** of nitrogen at 1862.1 psia. For the total test interval, the calculated leak rate was -21.41 **bbl/yr** of nitrogen at 1849 psia.

The leak rates calculated are negative because the pressure change ratio is greater than the corresponding volume change ratio.

Since negative nitrogen leak rates are not plausible, the data appear to indicate a zero **bbl/yr** leak rate. The negative values calculated are believed to result from inaccuracies in measurements. Interface depth measurements are considered the least accurate of all measurements taken and a 1 ft error here will correspond to an error in calculated nitrogen leak rate of 23.5 **bbls/yr**. Errors in pressure and **borehole** volume are believed to affect the calculated nitrogen leak rate no more than 2.0 **bbl/yr**. It has been proposed in Reference 12 that it is reasonable to assume a value of ten for the ratio of volumetric nitrogen to oil leak rates. Thus, the above errors in calculated nitrogen leak rates correspond to errors in oil leak rates of 2.5 **bbls/yr**. This is well within the DOE leak rate criterion of 100 **bbls/yr** of oil.

### Conclusions

Test results indicate no reason to question the integrity of Cavern Bayou Choctaw 102. During shut-in following pressurization to maximum test pressure, cavern pressures decreased slightly with time. During shut-in following depressurization to maximum operating pressure, cavern pressures increased slightly with time. These characteristics are typically observed in caverns with no known significant leaks. Calculations based on data collected during this test indicate that the oil leak rate of Cavern 102 is approximately zero **bbls/yr** of oil.

## References

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3. Crawford, R. F., Letter to M. Waggoner, U. S. Department of Energy Strategic Petroleum Reserve, Subject: Addendum to Well History **102A-Bayou** Choctaw, August 26, 1981.
4. Sonar/Caliper Report for Bayou Choctaw Cavern 102 by Dowell **11/19/84**.
5. **Goin**, Kenneth L., **SAND82-1751**, "Nitrogen Leak Test of Department of Energy Strategic Petroleum Reserve (**DOE/SPR**) Well 102A at Bayou Choctaw," Sandia National Laboratories, Albuquerque, New Mexico, March 1983.
6. "Workover and Testing Procedures for Bayou Choctaw Well **102A**," dated August 21, 1984.
7. **PB/KBB**, Inc., PERF-O-LOG, Inc., X-Y Caliper Log, Well 102, Bayou Choctaw, October 30, 1984.
8. PB/KBB, Inc., PERF-O-LOG, Inc., Interface Survey, Well No. 102, Bayou Choctaw, December 19, 1984.
9. PB/KBB, Inc., Micro Gage, Inc., Interface Survey, Well No. 102, Bayou Choctaw, December 27, 1984.
10. PB/KBB, Inc., Micro Gage, Inc., Interface Survey, Well No. 102, Bayou Choctaw, January 3, 1985.
11. PB/KBB, Inc., Micro Gage, Inc., Interface Survey, Well No. 102, Bayou Choctaw, January 9, 1985.
12. **Goin**, Kenneth L., "Proposed Leak Rate Acceptance Criterion for SPR Cavern Wells," SL-SPR-EE-00-24, October 11, **1983**.

Table I.  
SEQUENCE OF TESTING EVENTS

<u>Date</u>	<u>Event</u>
11/26/84	Began instrumentation hook up and preparation.
<u>CAVERN PRESSURE TEST WITH BRTNE</u>	
11/28/84	Injected 8280 bbls of brine - pressure to 618.4 psig.
11/30/84	Injected an additional 1388 bbls of brine - pressure to 705.9 psig.
11/30/84	Began 7-day cavern shut-in at maximum test pressure.
12/07/84	End of 7-day shut-in - pressure 699.3 psig.
12/07/84	Cavern bled down to 576.5 psig. Ejected 1204 bbls.
12/07/84	Began 11-day cavern shut-in at maximum operating pressure.
12/18/84	End of 11-day shut-in - pressure 592.1 psig.
<u>WELL PRESSURE TEST WITH NITROGEN</u>	
12/18/84	Injected 32,033 ft <sup>3</sup> (STP) of nitrogen, I/F @ 1460 ft, 1325.6 psig.
12/19/84	Injected 30,777 ft <sup>3</sup> (STP) of nitrogen, I/F @ 2499 ft, 1736 psig.
12/19/84	Injected 11,362 ft <sup>3</sup> (STP) of nitrogen, I/F @ 2532 ft, 1751 psig.
12/21/84	Injected 1186 bbls of brine, I/F not measured, 1825.6 psig.
12/27/84	I/F measured, 2520 ft, 1834.3 psig.
01/03/85	I/F measured, 2519 ft, 1847.4 psig.
01/09/85	I/F measured, 2518.5 ft, 1858.3 psig.
01/09/85	Cavern depressurized - test complete.

NOTE: All pressure readings were on the 14 x 10-3/4-inch annulus at the wellhead.

Table II  
BAYOU CHOCTAW 102

SUMMARY OF NITROGEN-BRINE INTERFACE RESULTS AND NITROGEN LOSS RATE CALCULATIONS

Date	Time	Hours From Test Start	N <sub>2</sub> Well- head Press. PSIG.	N <sub>2</sub> Brine Interface From Log, FT	Interface Movement from Log Overlay, FT	(1) Hole Vol. at I/F Depth, BBL/FT	(2) Time Interval Days N <sub>2</sub> Loss/Rate BBL/yr
12/21/84	16:20	88:20	1825.6				
12/27/84	11:00	227:00	1834.3	2520			
1/03/85	12:00	396:00	1847.4	2520	-1.0	0.452	7.042 -17.34
1/09/85	11:00	539:00	1858.3	2519	-0.5	0.452	5.958 -23.63
1/09/85	11:00	539:00	1858.3	2519	-1.5	0.452	13.00 -21.41

Leak rate calculations based on 11/6/84 caliper survey, Ref. 4 and using Eg. (4), p. 23 of Ref. 1.

1. Interval 1 from 12/27/84 to 1/3/85, interface moved up 1 ft.

$V_o = 111.02$  BBL/yr; AV for 1-ft I/F movement = -0.452 BBL/yr;  $P_o = 1834.3$  psig + 14.7 = 1849 psia  
AP = +13.1 psia

$$\text{Leak rate} = V_o \left( -\frac{\Delta P}{P_o} - \frac{\Delta V}{V_o} \right) = 111.02 \left( -\frac{13.1}{1849} - \frac{-0.452}{111.02} \right) \times \frac{365}{7.042} = -17.34 \text{ BBL/yr}$$

2. Total interval from 12/27/84 to 1/09/85, interface moved up 1.5 ft.

$V_o = 111.02$  BBL/yr; AV for 1.5-ft I/F movement = -0.678 BBL/yr;  $P_o = 1849.0$  psia

AP = +24.0 psia

$$\text{Leak rate} = V_o \left( -\frac{\Delta P}{P_o} - \frac{\Delta V}{V_o} \right) = 111.02 \left( -\frac{24.0}{1849} - \frac{-0.678}{111.02} \right) \times \frac{365}{13.0} = -21.41 \text{ BBL/yr}$$

- (1) From data provided in reference 4.  
(2) Calculated from Eq. (4) of reference 1.

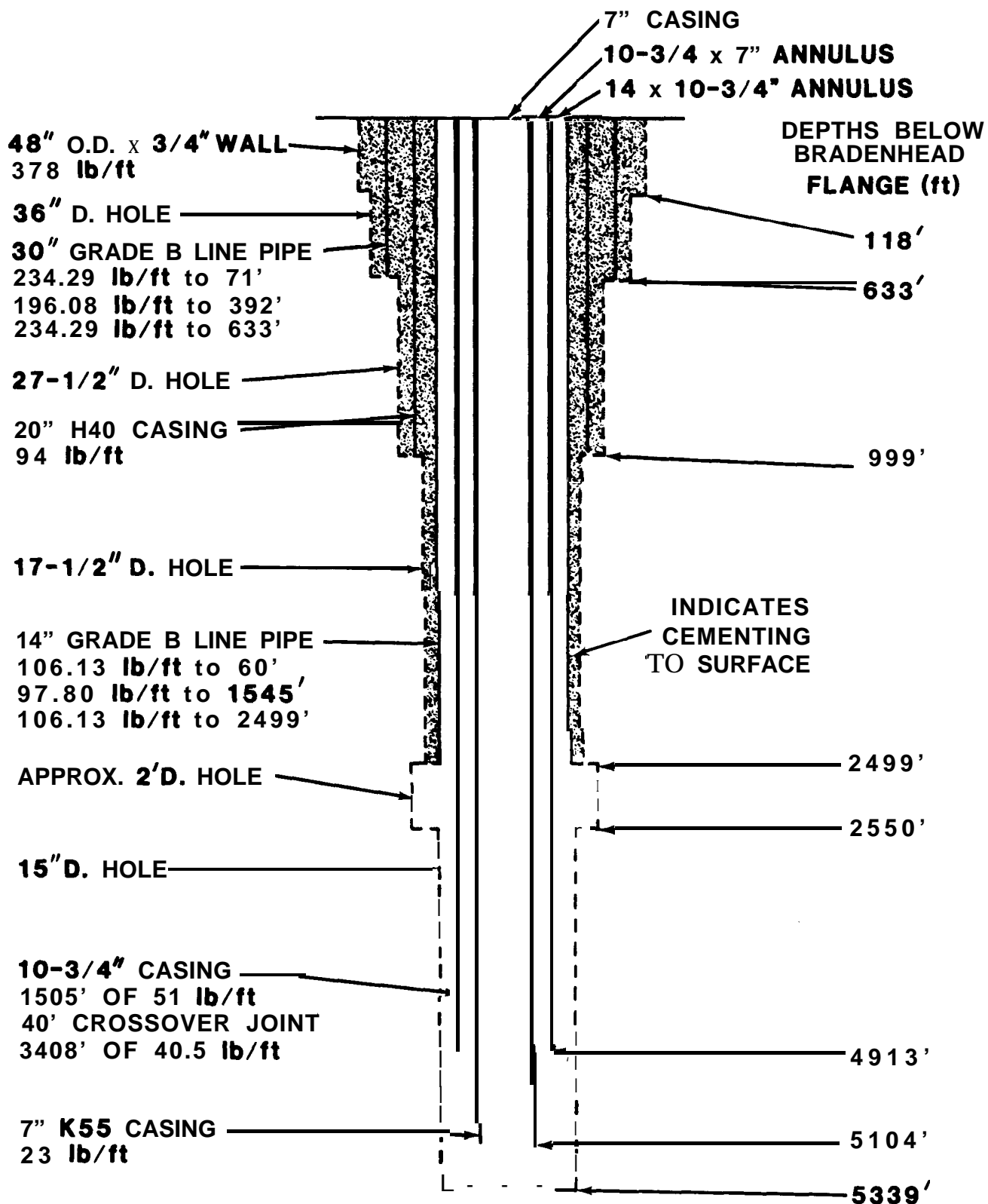


Figure 1. Schematic of well with 7-inch and 10-3/4-inch hanging strings to depths existing during the test.

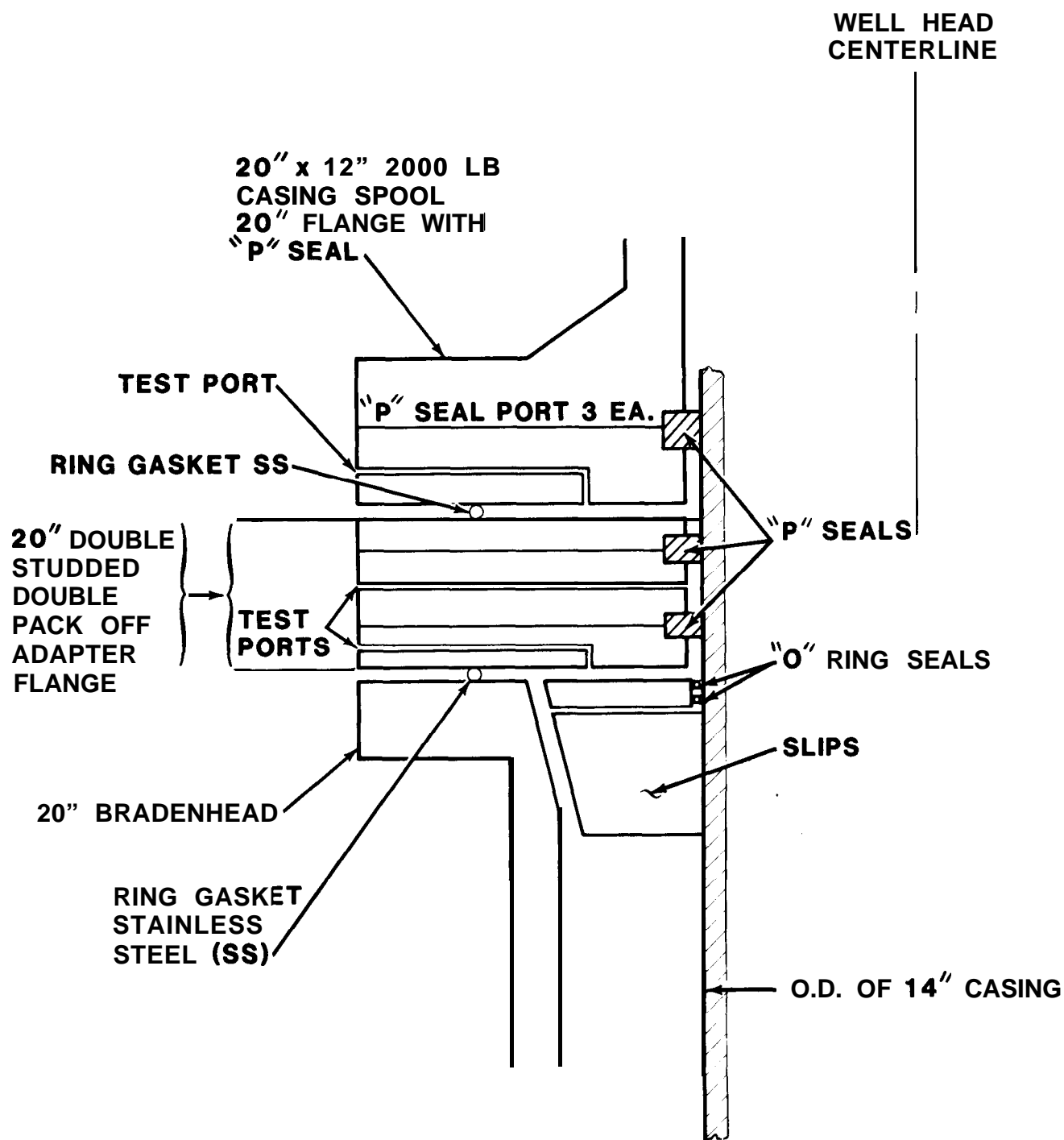


Figure 2. Schematic of 14-inch seal arrangement,

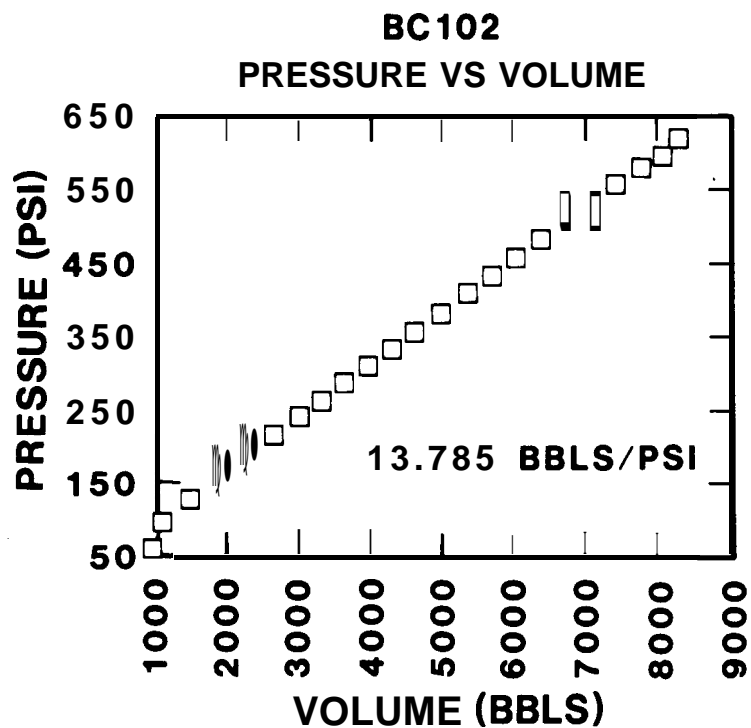
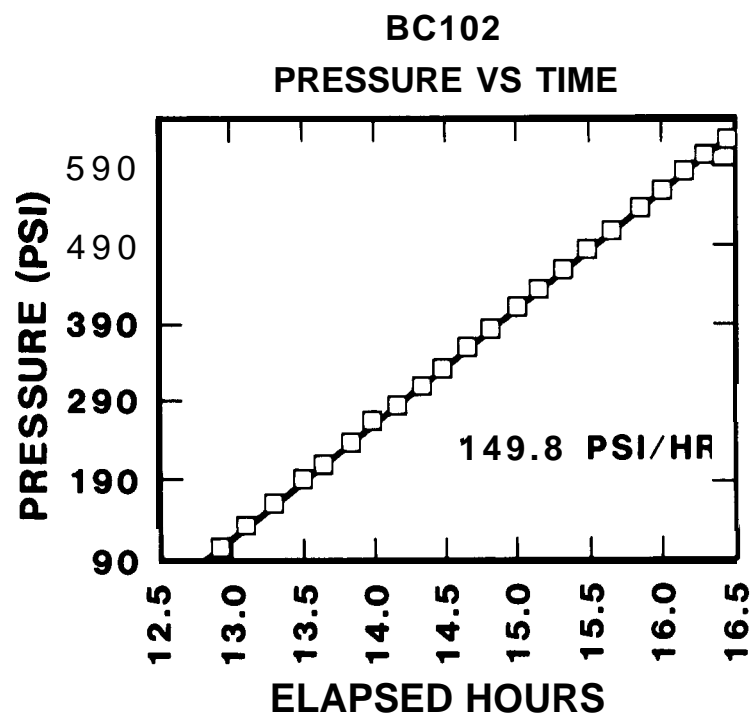


Figure 3. Pressure vs. time and pressure vs. volume for brine pressurization, Step 1.

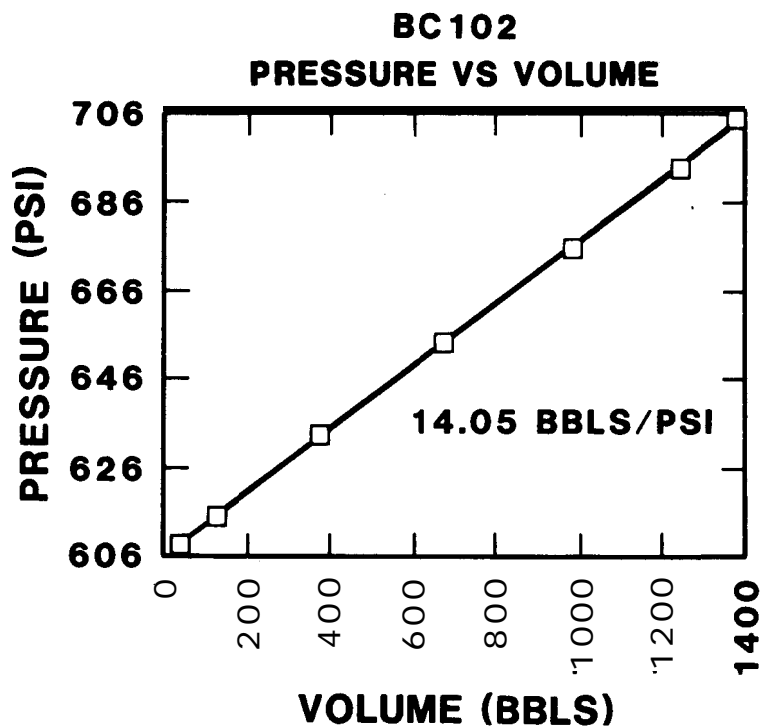
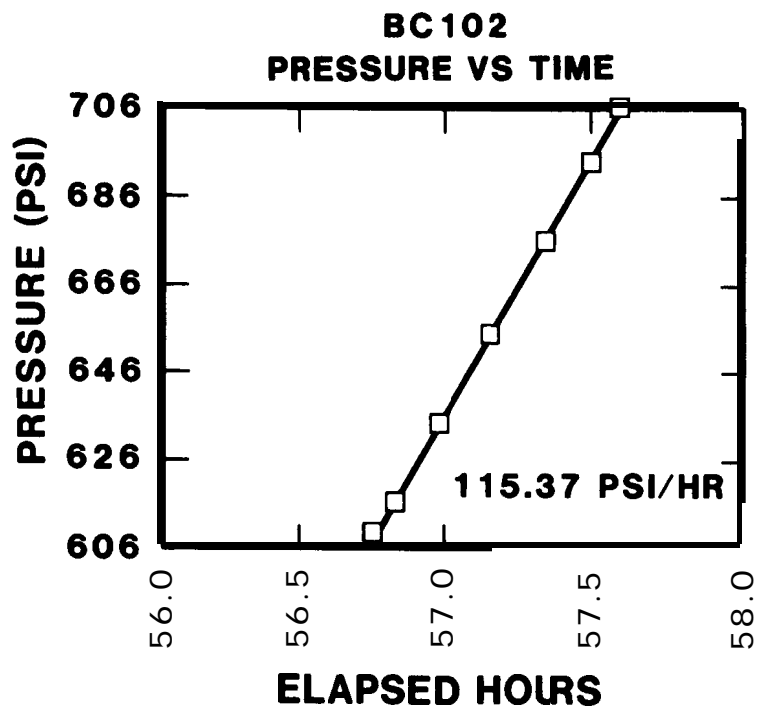


Figure 4. Pressure vs. time and pressure vs. volume for brine pressurization, Step 2.

BC102  
PRESSURE VS TIME

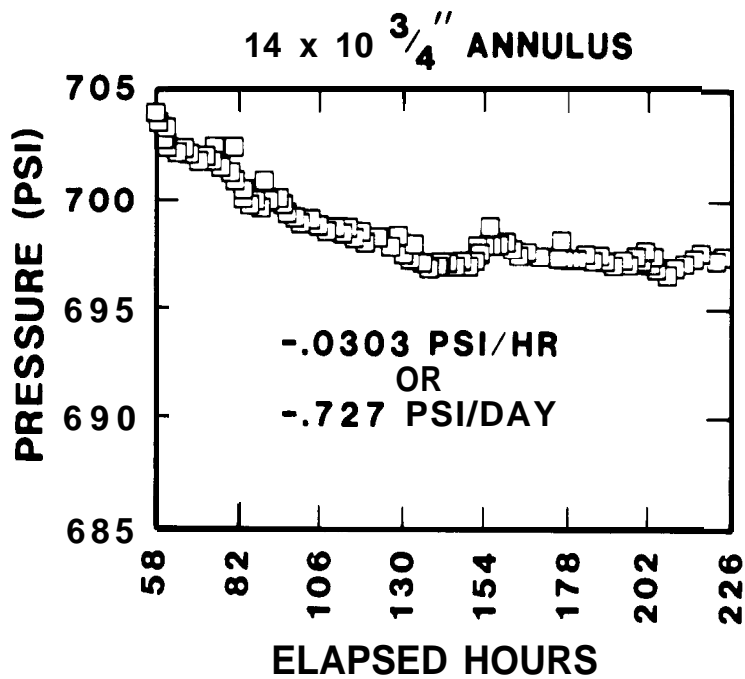
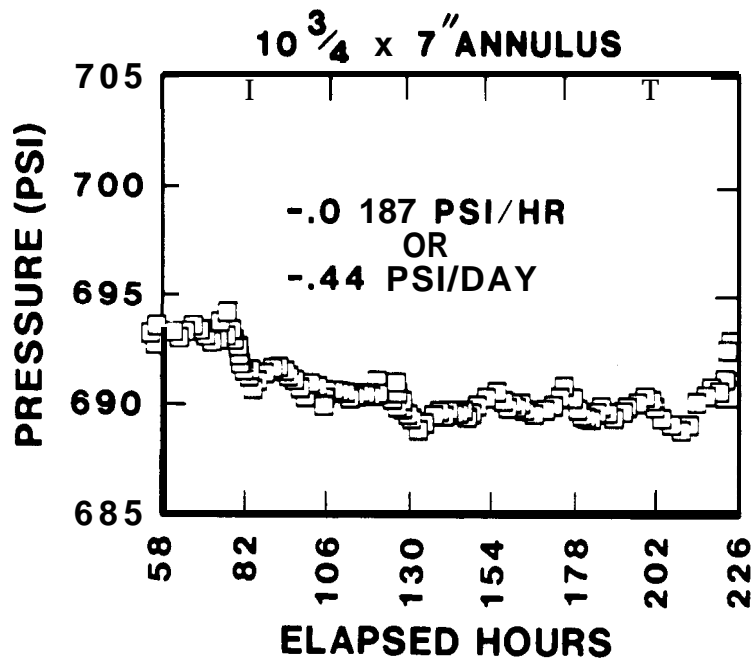


Figure 5. Pressure vs. time plots for the brine pressure test at maximum test pressure.

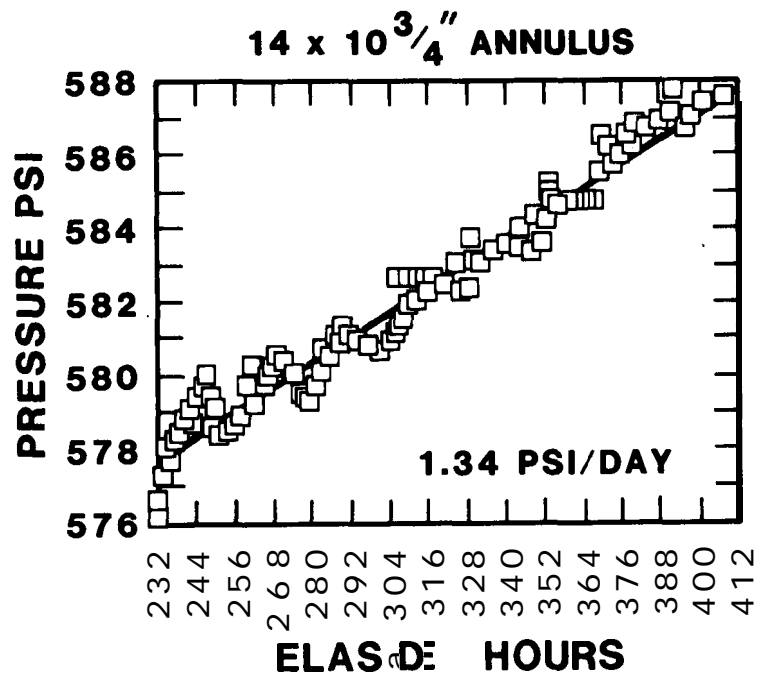
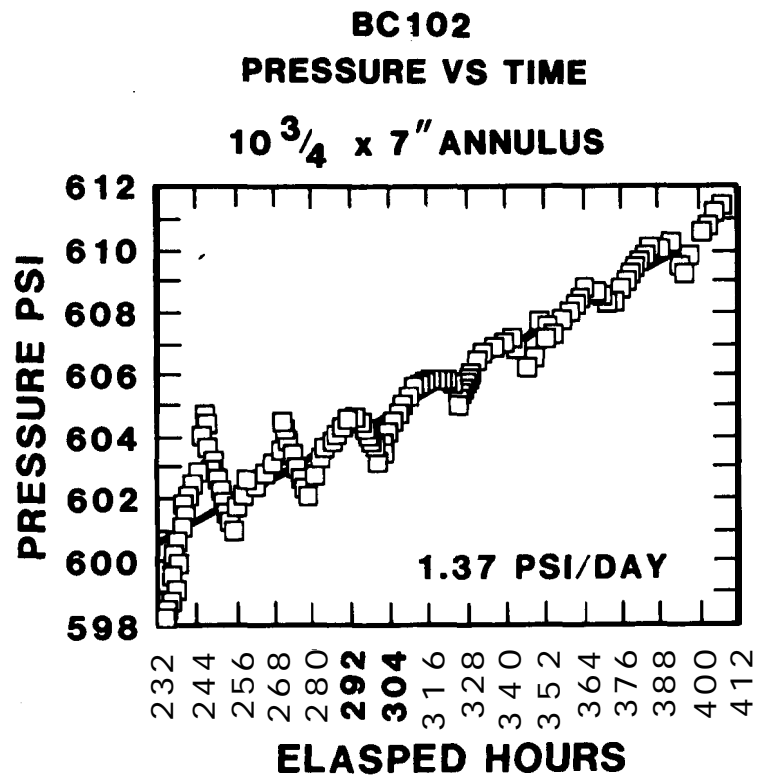
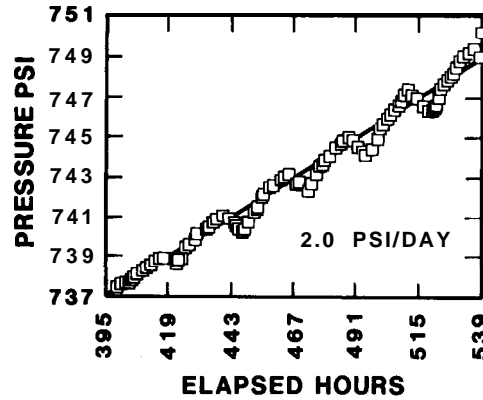


Figure 6 Pressure vs. time plots for the brine pressure test at maximum operating pressure.

**BC102**  
**PRESSURE vs TIME**  
**FOR 10 3/4 x 7" BRINE ANNULUS**



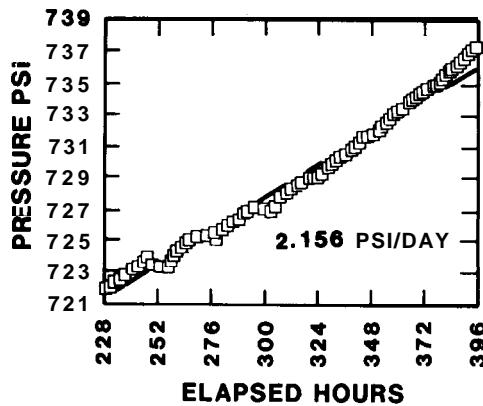
START TEST WEEK TWO  
 @1200 HRS 1-3-85  
 (396:00 HRS)

LEAST SQUARES SOLUTION

$$\text{PRESSURE} = 703.9 + 8.332\text{E-}2 \times \text{HOURS}$$

$$R^2 = .9772$$

END TEST @1100 HRS  
 1-9-85 (539:00 HR)  
 N<sub>2</sub> - BRINE INTERFACE @25 18.5'



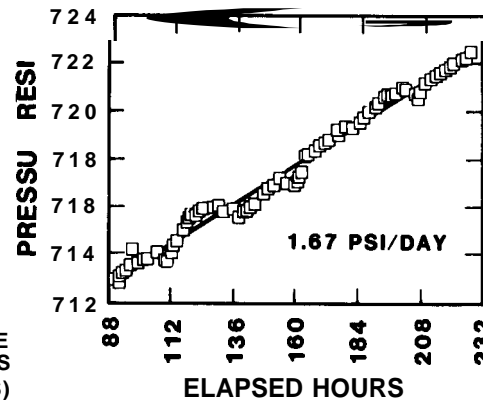
START TEST WEEK ONE  
 @ 1100 HRS 12-2 7-84  
 (227:00 HRS)

LEAST SQUARES SOLUTION

$$\text{PRESSURE} = 700.7 + 8.981\text{E-}2 \times \text{HOURS}$$

$$R^2 = .983$$

END TEST WEEK ONE  
 81200 HRS 1-3-85 (396:00 HRS)  
 N<sub>2</sub> - BRINE INTERFACE 25 19'



START TEMPERATURE  
 STABILIZATION @16:20 HRS  
 12-2 1-84 (88:20 HRS)

LEAST SQUARES SOLUTION

$$\text{PRESSURE} = 708.5 + 8.979\text{E-}2 \times \text{HOURS}$$

$$R^2 = .986$$

END TEMPERATURE STABILIZATION  
 81100 HRS 12-27-84 (227:00 HOURS)  
 N<sub>2</sub> - BRINE INTERFACE @2520'

Figure 7. Pressure vs. time for brine annulus during nitrogen test.

**BC102**  
**PRESSURE vs TIME**  
**FOR 10 3/4 x 14" NITROGEN ANNULUS**

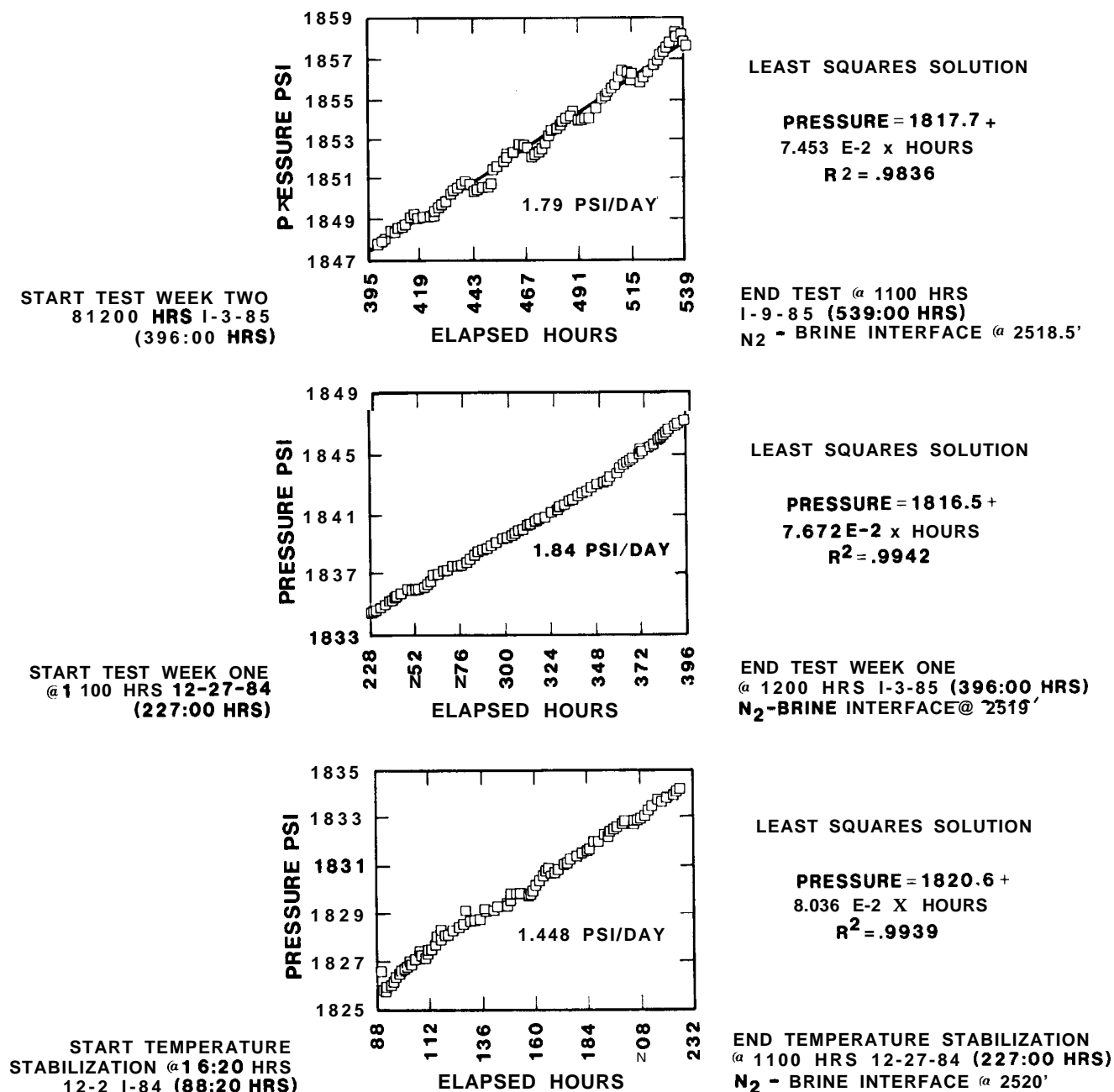


Figure 8. Pressure vs. time for nitrogen annulus during nitrogen test.

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